

Increasing coupling properties of locomotive by magnetizing contact area of wheel with rail

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Abstract. The authors of the paper consider a section of the magnetic circuit, which includes a band of a wheel pair, a railhead and an air gap between them. The parameters of the magnetic field and magnetic resistance between the wheel and the rail are obtained. Attention is paid to the decrease in the magnetic permeability of saturated steel regions and to the change in the magnetic susceptibility of the contact regions at high temperatures in the contact spot. The epicenters of the magnetic field concentration at different modes of magnetization are determined taking into account the change in the wheel position relative to the rail.

1. Introduction

The effective operation of rail transport is determined by the coupling capabilities of locomotives. The lack of traction is particularly acute when the train is started and accelerated on sections with steep slopes. Significant biases of the way are characteristic for career rail transport; difficult operating conditions contribute to spinning of wheels when the locomotive moves at low speeds in the "traction" mode. At the same time, energy losses in the mechanical part of the traction drive increase. In [1], the authors solve the problem of increasing the energy saving of the traction drive of the locomotive. Within the framework of this task, a method for improving the coupling properties by magnetizing the contact of a wheel with a rail was considered.

A section of the magnetic circuit is considered, which includes a band of a wheel pair, a railhead and an air gap between them. The magnetic characteristic is accepted for the material bandage steel with a saturation induction of 1.3 T; full saturation corresponds to an induction of 1.5 T. Magnetization is carried out by a constant magnetic field; working and adjacent surfaces participate in the flow of magnetic flux between the wheel and the rail. Magnetic field lines pass through a contact spot or an air gap. To further define flows, the characteristic surfaces on the wheel and rail are distinguished; and the surfaces border each other on fillets. Table 1 lists conditions for the concentration of magnetic flux on surfaces. These conditions are divided into geometric and magnetic. In the final analysis, they determine the magnitude of magnetic resistance of contact zone of the wheel with the rail.

Geometric influence arises from the movement of ferromagnetic bodies and changes in the air gap. The resistance of steel is strongly affected by field induction; in the saturated areas of the wheel and rail the magnetic permeability assumes small values. This contributes to the deviation of the magnetic flux; it traverses saturated regions by a longer trajectory with less magnetic resistance. In the gap, the magnetic flux passes through the air with a constant magnetic permeability, so the gap resistance mainly depends on its length.



Table 1. Conditions for distribution of magnetic flux between surfaces

compound parts of surfaces of rail head	half of fillet, flange of band of locomotive wheel	half of fillet, wheel thread of band of locomotive wheel	Chamfer, outer edge of band of locomotive wheel
half of internal fillet, inner face of head	small gap between the flange and the rail when the steel is saturated on the wheel threads; flange contact	saturation of steel on the wheel thread when the position of the wheel is close to the central	–
half of internal and external fillets, wheel thread	single-point flange contact, rail sloping and release, formation of a shelf of wear on the rail head, climbing up of flange	in normal conditions, the main magnetic flux passes through these surfaces (the regime is disrupted when the wheel thread is separated and the wheel is climbing up)	width of track, close to maximum, considerable wear of flanges, climbing up of second wheel flange
half of external fillet, inner face of head	–	saturation of steel on the wheel thread when the position of the wheel is close to the central	significant gap between the flange and the rail when the steel is saturated on the wheel threads

Since a constant ferromagnetic contact is maintained between the wheel and the rail, it can be assumed that the entire magnetic flux is composed of flows passing through the wheel thread and the flange of the wheel, and the scattering fluxes are insignificant. Due to the large air gap, the flow through the outer edge of the wheel can be attributed to the scattering fluxes.

At temperatures above the Curie point, the ferromagnetic material acquires the properties of a paramagnet. For iron, the Curie temperature is 770 °C, and for various grades of rail steel is in the range from 630 to 790 °C. When the locomotive wheel slides, the temperature in contact of the wheel with the rail is 400 ... 600 °C, the thermal energy dissipates to a depth of up to 15 mm, and the material undergoes structural and morphological changes [2, 3]. The maximum temperature reaches 680 °C, the temperature flash is on the subsurface layer of protrusions [4-7].

Thus, in severe operating conditions, the magnetic susceptibility of the near contact areas of the wheel may vary due to the elevated temperature in the contact spot. This feature is taken into account by layerwise subdivision of the contact region and by setting the variable magnetic characteristics of the steel.

2. Materials and methods

Surfaces of the wheel and rail are characterized by complex geometry and nonlinearity of magnetic properties. Solution methods using the theory of circuits have a number of assumptions and do not provide high accuracy [8, 9]. The use of simplified mathematical models can be limited to pre-project calculations. Field methods for calculating magnetic systems are based on solving Maxwell's differential equations [10, 11]:

$$\nabla \times \vec{H} = \vec{J}; \quad \nabla \cdot \vec{B} = 0 \quad (1)$$

The analytical solution is of little use for practical problems. For the magnetic field analysis, a numerical method is used using the software Ansys Maxwell [11]. Figure 2 shows the distribution of

magnetic field in the contact area of the new wheel with the worn rail at different wheel positions.

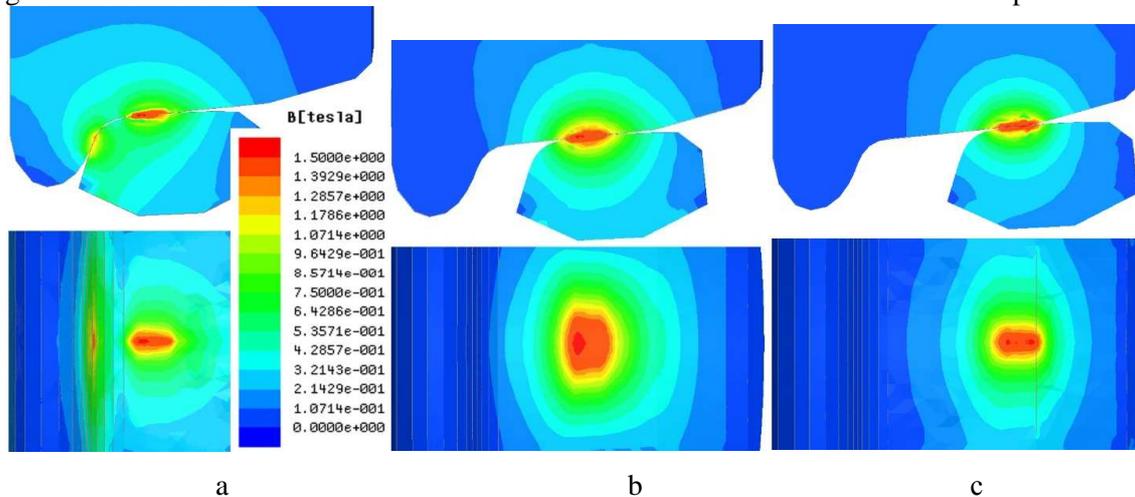


Figure 1. Magnetization of the contact area of a new wheel with a worn rail ($U_m = 257$ A): a - flange contact; b - central position of the wheel; c - the largest gap between the flange and the rail.

A distinctive feature of the considered section of the magnetic circuit is that the contact of ferromagnetic bodies is insignificant and surrounded by an air gap of a wedge shape. This creates the prerequisites for distortion of the calculated values due to the singularity. To reduce the error, a local increase in the accuracy of the grid is used. Increasing the number of iterations leads to an improvement in the grid model. With each new passage, the grid generator adapts the model until the energy balance meets the accuracy criterion.

3. Distribution of the magnetic field parameters in the zone of contact of the wheel with the rail

The wheel with the rail is mainly contacted by the rolling surfaces, so the most of the magnetic flux flows through the top of the railhead. This is especially expressed on contact when the clearance between the rail and the wheel flange assumes the maximum values, i. e. the other rail is in the state of the flange contact. The profile of the wheel is wider than the railhead, this geometric feature contributes to the fact that under normal operating conditions, power lines can connect the rolling surface of the wheel to any of three considered rail surfaces.

The contact of the top of the railhead with the flange and the chamfering area of the wheel occurs in the limit operating conditions: single-point flange contact of wear wheel, rail sloping and release, formation of a shelf of wear on the railhead, wheeling of flange on the railhead. These modes are accompanied by a detachment of the rolling surface of the wheel from the railhead [12-14], which facilitates the reorientation of a significant part of the magnetic flux from the rolling surface to adjacent surfaces.

The loss of stability of wheels is typical for empty and low-loaded cars, at high speeds. Due to the considerable axial load, locomotives have a margin of stability of the wheel from rolling in the flange onto the railhead [15].

Figure 2 shows parameters of the magnetic field. In the process of changing the transverse position of the wheel relative to the rail, magnetic stress was maintained in the considered section of the chain in the range of 250 ... 260A, 120 ... 130A, 60 ... 65A. The induction distribution along the wheel profile, magnetic flux distribution and magnetic permeability in the gap between the wheel and the rail were followed.

The magnetic stress at the circuit section was determined by integrating the tangential component of the magnetic field strength H along the bypass contour l .

$$U_m = \oint_l H dl \quad (2)$$

The magnetic permeability μ is determined by the ratio of field induction and strength, characterizes the distribution of magnetic resistance.

$$[\mu] = \frac{\partial \vec{B}}{\partial H} \quad (3)$$

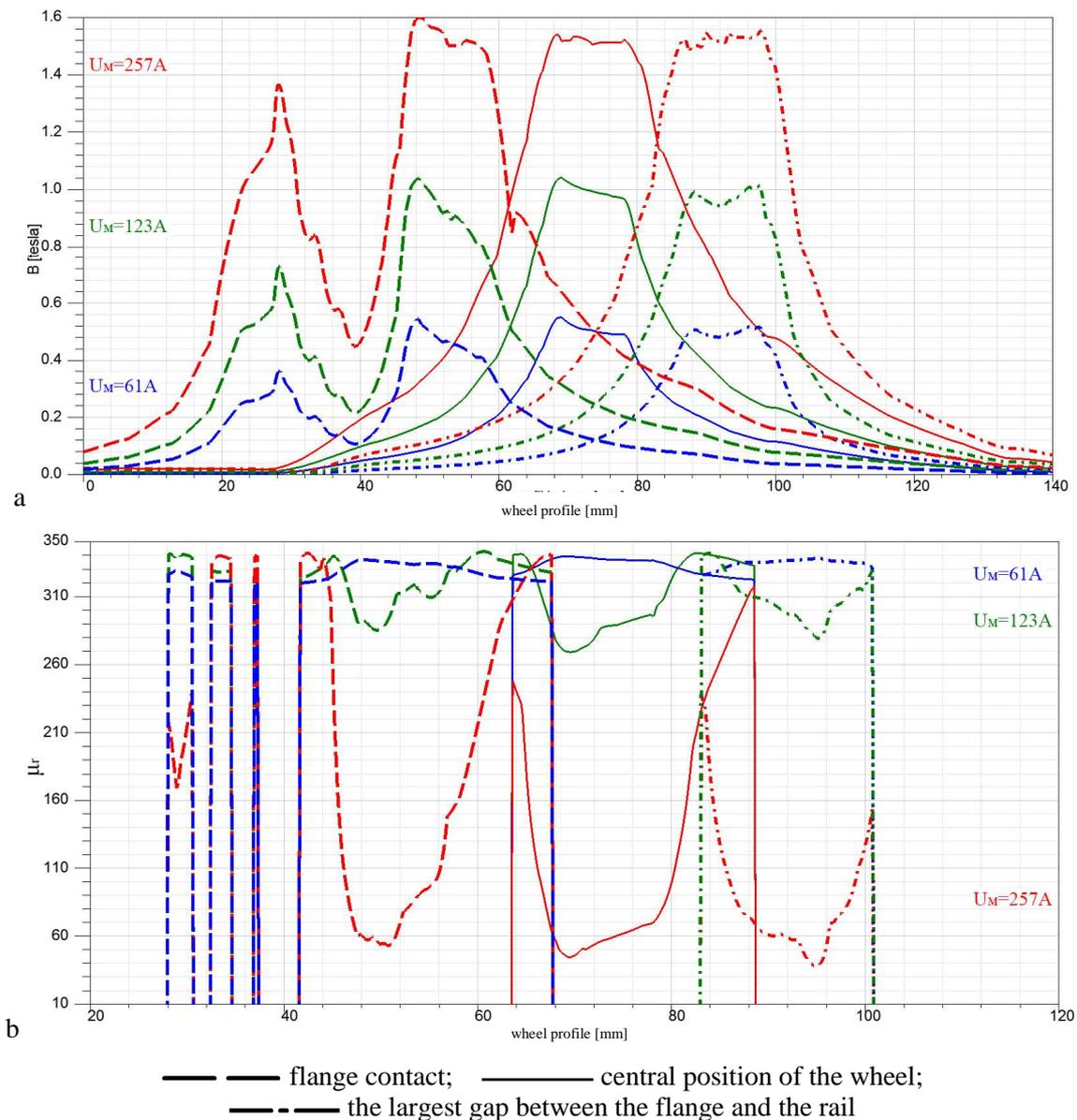


Figure 2. The effect of magnetization modes and changes in the transverse position of the new wheel relative to the worn rail on parameters of the magnetic field in the contact zone: a - induction on the wheel surface; b - the relative permeability in the gap.

4. Conclusion

Results of calculations show that saturation of surfaces occurs in different ways. With a two-point flange contact, the wheel flange is saturated 1.4 ... 2 times less than the rolling surface. This difference is particularly expressed for worn wheels and depends mainly on the area of the contact spot. The flux of magnetic induction through the surface of a given area was determined as the scalar product of the vector of magnetic induction by the area vector. With a two-point contact, 60 to 70% of the magnetic

flux passes through the rolling surface of the wheel. This value increases to 98% with an air gap between the wheel flange and the rail.

To saturate the rolling surface of the wheel, it is required to apply a magnetic stress of 180 A to the contact zone, and 250 A for complete saturation. The wear of surfaces, the variation of transverse position of the wheel pair in the track, the saturation of the contact zone, the manifestation of paramagnetic properties in the near contact areas affect the distribution of magnetic field in the contact zone of the locomotive wheels with rails. The change in the parameters of magnetic field should be used as the basis for the functioning of feedback coupling control systems.

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